Previous Lectures

- Multithreading
  - Memory Layout
  - Kernel vs User threads
  - Representation in OS
  - Difference between thread and process
  - Thread scheduling
  - Mapping between user and kernel threads
- Multithreading in Java
  - Thread creation
  - API
  - Thread lifecycle
  - Thread collaboration/synchronization
- Hands-on experience after this: Unix process system calls and signals, Java threads

Chapter 6: CPU Scheduling

- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Multiple-Processor Scheduling
- Real-Time Scheduling
- Algorithm Evaluation

Basic Concepts

- Maximum CPU utilization obtained with multiprogramming
- CPU-I/O Burst Cycle – Process execution consists of a cycle of CPU execution and I/O wait.
- CPU burst distribution

Alternating Sequence of CPU And I/O Bursts

Histogram of CPU-burst Times

CPU Scheduler

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them.
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state.
  2. Switches from running to ready state.
  3. Switches from waiting to ready.
  4. Terminates.
- Scheduling under 1 and 4 is nonpreemptive.
- All other scheduling is preemptive.
Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- Dispatch latency – time it takes for the dispatcher to stop one process and start another running.

Scheduling Criteria

- CPU utilization – keep the CPU as busy as possible
- Throughput – # of processes that complete their execution per time unit
- Turnaround time – amount of time to execute a particular process
- Waiting time – amount of time a process has been waiting in the ready queue
- Response time – amount of time it takes from when a request was submitted until the first response is produced, not output (for time-sharing environment)

Optimization Criteria

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

First-Come, First-Served (FCFS) Scheduling

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>24</td>
</tr>
<tr>
<td>P₂</td>
<td>3</td>
</tr>
<tr>
<td>P₃</td>
<td>3</td>
</tr>
</tbody>
</table>

Suppose that the processes arrive in the order: P₁, P₂, P₃
The Gantt chart for the schedule is:

```
0 15 30
P₁ P₂ P₃
```

- Waiting time for P₁ = 0; P₂ = 0; P₃ = 3
- Average waiting time: (0 + 0 + 3)/3 = 1

Shortest-Job-First (SJR) Scheduling

- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time.
- Two schemes:
  - nonpreemptive – once CPU given to the process it cannot be preempted until completes its CPU burst.
  - preemptive – if a new process arrives with CPU burst length less than remaining time of current executing process, preempt. This scheme is know as the Shortest-Remaining-Time-First (SRTF).
- SJF is optimal – gives minimum average waiting time for a given set of processes.

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order P₂, P₃, P₁.
The Gantt chart for the schedule is:

```
0 9 30
P₂ P₃ P₁
```

- Waiting time for P₁ = 6; P₂ = 0; P₃ = 3
- Average waiting time: (6 + 0 + 3)/3 = 3
- Much better than previous case.
- Convoy effect short process behind long process
Example of Non-Preemptive SJF

<table>
<thead>
<tr>
<th>Process</th>
<th>Arrival Time</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>0.0</td>
<td>7</td>
</tr>
<tr>
<td>P₂</td>
<td>2.0</td>
<td>4</td>
</tr>
<tr>
<td>P₃</td>
<td>4.0</td>
<td>1</td>
</tr>
<tr>
<td>P₄</td>
<td>5.0</td>
<td>4</td>
</tr>
</tbody>
</table>

- SJF (non-preemptive)
- Average waiting time = (0 + 6 + 3 + 7)/4 - 4

Example of Preemptive SJF

<table>
<thead>
<tr>
<th>Process</th>
<th>Arrival Time</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>0.0</td>
<td>7</td>
</tr>
<tr>
<td>P₂</td>
<td>2.0</td>
<td>4</td>
</tr>
<tr>
<td>P₃</td>
<td>4.0</td>
<td>1</td>
</tr>
<tr>
<td>P₄</td>
<td>5.0</td>
<td>4</td>
</tr>
</tbody>
</table>

- SJF (preemptive)
- Average waiting time = (9 + 1 + 0 + 2)/4 - 3

Determining Length of Next CPU Burst

- Can only estimate the length.
- Can be done by using the length of previous CPU bursts, using exponential averaging.

1. \( t \) = actual length of \( n \) CPU burst
2. \( \tau_n \) = predicted value for the next CPU burst
3. \( 0 \leq \alpha \leq 1 \)

Prediction of the Length of the Next CPU Burst

Examples of Exponential Averaging

- \( \alpha = 0 \)
  - \( t_{n-1} \) = \( t_n \)
  - Recent history does not count.

- \( \alpha = 1 \)
  - \( t_{n-1} \) = \( t_n \)
  - Only the actual last CPU burst counts.

If we expand the formula, we get:

\[
\tau_{n+1} = \alpha t_n + (1 - \alpha) \tau_n \quad \tau_1 = \ldots \\
= \alpha^{n+1} t_1 + \ldots + \alpha \quad \text{since both } \alpha \text{ and } (1 - \alpha) \text{ are less than or equal to 1, each successive term has less weight than its predecessor.}

Priority Scheduling

- A priority number (integer) is associated with each process.
- The CPU is allocated to the process with the highest priority (smallest integer = highest priority),
  - preemptive
  - nonpreemptive

SJF is a priority scheduling where priority is the predicted next CPU burst time.

Problem = Starvation – low priority processes may never execute.

Solution = Aging – as time progresses increase the priority of the process.
Round Robin (RR)

- Each process gets a small unit of CPU time (time quantum), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
- If there are \( n \) processes in the ready queue and the time quantum is \( q \), then each process gets \( 1/n \) of the CPU time in chunks of at most \( q \) time units at once. No process waits more than \((n-1)q\) time units.
- Performance
  - \( q \) large \(\Rightarrow\) FIFO
  - \( q \) small \(\Rightarrow\) \( q \) must be large with respect to context switch, otherwise overhead is too high.

Example of RR with Time Quantum = 20

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>53</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>17</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>68</td>
</tr>
<tr>
<td>( P_4 )</td>
<td>24</td>
</tr>
</tbody>
</table>

- The Gantt chart is:

Typically, higher average turnaround than SJF, but better response.

Time Quantum and Context Switch Time

Turnaround Time Varies With The Time Quantum

Multilevel Queue

- Ready queue is partitioned into separate queues: foreground (interactive) background (batch)
- Each queue has its own scheduling algorithm, foreground – RR background – FCFS
- Scheduling must be done between the queues.
  - Fixed priority scheduling: (i.e., serve all from foreground than from background). Possibility of starvation.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., 80% to foreground in RR
  - 20% to background in FCFS

Multilevel Queue Scheduling
Multilevel Feedback Queue

- A process can move between the various queues; aging can be implemented this way.
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when that process needs service

Example of Multilevel Feedback Queue

- Three queues:
  - \( Q_0 \) – time quantum 8 milliseconds
  - \( Q_1 \) – time quantum 16 milliseconds
  - \( Q_2 \) – FCFS
- Scheduling
  - A new job enters queue \( Q_0 \) which is served FCFS. When it gains CPU, job receives 8 milliseconds. If it does not finish in 8 milliseconds, job is moved to queue \( Q_1 \).
  - At \( Q_1 \) job is again served FCFS and receives 16 additional milliseconds. If it still does not complete, it is preempted and moved to queue \( Q_2 \).

Multilevel Feedback Queues

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.
- Homogeneous processors within a multiprocessor.
- Load sharing
- Asymmetric multiprocessing – only one processor accesses the system data structures, alleviating the need for data sharing.

Real-Time Scheduling

- Hard real-time systems – required to complete a critical task within a guaranteed amount of time.
- Soft real-time computing – requires that critical processes receive priority over less fortunate ones.

Dispatch Latency
Algorithm Evaluation

- Deterministic modeling – takes a particular predetermined workload and defines the performance of each algorithm for that workload.
- Queueing models
- Implementation

Evaluation of CPU Schedulers by Simulation

Solaris 2 Scheduling

Windows 2000 Priorities